two or more of Ti, V, Mo, W, Cr, Mn, or Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$." is amended to

-- a magnetic thin film of the present invention is characterized in that it comprises a substrate, and $Co_2MGa_{1-x}Al_x$ thin film formed on said substrate, and said $Co_2MGa_{1-x}Al_x$ thin film has $L2_1$ or B2 single phase structure, M of the thin film consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$. --.

(2) Specification page 5, lines 15 – 17 and 22 – 24, page 6, lines 10 – 12 and 26 – 28, page 7, lines 16 – 18, page 10, lines 5 – 7, 15 – 17, 23 – 25, and 27 – 29, page 11, lines 9 – 11, 14 – 16, and 18 – 20, page 12, lines 7 – 9, 12 – 15, and 25 – 27, page 13, lines 6 – 8, 9 – 11, 14 – 16, 19 – 21, and 28 – page 14, line 1, page 14, lines 14 – 17, 19 – 21, and 23 – 25, page 15, lines 3 – 5, 6 – 8, and 19 – 21, page 16, lines 14 – 16, 19 – 21, and 29 – page 17, line 2, page 17, lines 10 – 12, and 14 – 16, page 18, lines 8 – 10, page 21, lines 9 – 11, 13 – 16, and 20 – 22 (English translation page 5, [0019], line 33 – page 6, line 1, page 6, [0020], lines 6 – 9, [0022], lines 28 – 31, page 7, [0024], lines 16 – 18, page 8, [0026], lines 5 – 8, page 11, [0033], lines 6 – 8, [0035], lines 16 – 18, [0036], lines 28 – 30, [0037], line 35 – page 12, line 4, page 12, [0039], lines 13 – 15, [0040], lines 19 – 21, lines 24 – 26, page 13, [0042], lines 13 – 15, lines 20 – 22, page 14, [0043], lines 3 – 5, [0044], lines 18 – 20, lines 25 – 27, [0045], lines 32 – 34, page 15, [0046], lines 7 – 10, [0047], lines 26 – 29, lines 33 – 35, page 16, [0047], lines 6 – 8, [0048], lines 16 – 18, page 17, [0049], lines 1 – 3, page 18, [0052], lines 3 – 5, [0053], lines 8 – 10, [0054], lines 23 – 26, [0055], line 35 – page 19, line 2, page 19, [0055], lines 5 – 7, [0058], line 35 – page 20, line 2, page 23, [0068], lines 21 – 23, [0069], lines 28 – 30, and page 24, [0070], lines 1 – 3) "(where M is either one or two or more of Ti, V, Mo, W, Cr, Mn, or Fe, and <u>the</u> average valence electron concentration Z is $5.5 \leqq Z \leqq 7.5$, and $0 \leqq x \leqq 0.7$)" is amended to

-- (where M consists either of Mo, W, or Cr, or of two or more of Ti,

V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) --.

(3) Specification page 9, lines 12 – 15 (English translation page 10, [0030], lines 12 – 14) "M is either one or two or more of Ti, V, Mo, W, Cr, Mn, or Fe, and an average valence electron concentration Z in M is $5.5 \leqq Z \leqq 7.5$, and $0 \leqq x \leqq 0.7$," is amended to

-- M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$, --.

(4) Specification page 10, lines 27 – 29 (English translation page 11, [0037], line 35 – page 12, line1) "(where M is either one or two or more of Ti, V, Mo, W, Cr, Mn, or Fe)" is amended to

-- (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe) --.

(5) Specification page 11, lines 4 – 5 (English translation page 12, [0038], lines 6 – 7) "(where M is either one or two or more of Ti, V, Mo, W, Cr, Mn, or Fe)" is amended to

-- (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe) --.

(6) Claims page 22, Claim 1, lines 3 – 6 (English translation Claims page 25, Claim 1, lines 1 – 9) "characterized in that:

it comprises a substrate, and $Co_2MGa_{1-x}Al_x$ thin film formed on said substrate,

said $Co_2MGa_{1-x}Al_x$ thin film has $L2_1$ or B2 single phase structure,

M of said thin film is either one or two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and

<u>an</u> average valence electron concentration Z in said M is $5.5 \leqq Z \leqq 7.5$, and $0 \leqq x \leqq 0.7$." is amended to

-- characterized in that:

it comprises a substrate, and $Co_2MGa_{1-x}Al_x$ thin film formed

on said substrate,

said $Co_2MGa_{1-x}Al_x$ thin film has $L2_1$ or B2 single phase structure,

M of said thin film consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and

an average valence electron concentration Z in said M is $5.5 \leqq Z \leqq 7.5$, and $0 \leqq x \leqq 0.7$. --.

(7) Claims page 22, Claim 7, lines 3 – 5, pages 22 – 23, Claim 8, lines 2 – 5, page 23, Claim 12, lines 1 – 3, Claim 14, lines 3 – 5, Claim 15, lines 2 – 5, page 24, Claim 19, lines 1 – 3, Claim 21, lines 1 – 4, Claim 22, lines 1 – 3, page 25, Claim 26, lines 1 – 3, Claim 28, lines 1 – 4, Claim 29, lines 1 – 3, and page 26, Claim 33, lines 1 – 3 (English translation Claims page 26, Claim 7, lines 5 – 7, Claim 8, lines 4 – 6, Claim 12, lines 3 – 5, page 27, Claim 14, lines 4 – 6, Claim 15, lines 4 – 6, page 28, Claim 19, lines 3 – 5, Claim 21, lines 2 – 4, Claim 22, lines 4 – 6, page 29, Claim 26, lines 4 – 6, Claim 28, lines 2 – 4, Claim 29, lines 4 – 6, and page 30, Claim 33, lines 5 – 7) "(where M is either one or two or more of Ti, V, Mo, W, Cr, Mn, and Fe, an average valence electron concentration Z in M is $5.5 \leqq Z \leqq 7.5$, and $0 \leqq x \leqq 0.7$)" is amended to

-- (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, an average valence electron concentration Z in M is $5.5 \leqq Z \leqq 7.5$, and $0 \leqq x \leqq 0.7$) --.

6. List of Papers Attached:

(1) Specification, Substitute sheets, pages 5, 5/1, 6, 6/1, 7, 9, 9/1, 10, 10/1, 11, 11/1, 12, 12/1, 13, 13/1, 14, 14/1, 15, 15/1, 16, 17, 18, 21 (English translation, Substitute sheets, pages 5, 6, 7, 7/1, 8, 10, 10/1, 11, 11/1, 12, 12/1, 13, 13/1, 14, 14,/1, 15, 15/1, 16, 16/1, 17, 18, 18/1, 19, 19/1, 20, 23, 24)

(2) Claims, Substitute sheets, pages 22, 23, 24, 24/1, 25, 25/1, 26 (English translation, Substitute sheets, pages 25 to 30)

phase separation, thereby such a single phase alloy as $Co_2Fe_{0.4}Cr_{0.6}Al$ thin film which is expected to have half metal characteristics is hard to obtain.

Disclosure of the Invention

[0015] In view of the problems mentioned above, it is an object of the present invention to provide magnetic thin film of high spin polarizability and a magnetoresistance effect device and a magnetic device using the same.

[0016] The present inventors completed the present invention by finding that, as a result of fabrication of $Co_2MGa_{1-x}Al_x$ thin film, taking into consideration that Ga is an element having valence electrons equal to Al, and CoGa is not as stable as CoAl, this film is ferromagnetic at room temperature, and either $L2_1$ or B2 single phase structure can be prepared by not heating a substrate, or making film at 500℃ or lower, and further by annealing this thin film at 500℃ or lower.

[0017] In order to achieve the objects mentioned above, a magnetic thin film of the present invention is characterized in that it comprises a substrate, and $Co_2MGa_{1-x}Al_x$ thin film formed on said substrate, and said $Co_2MGa_{1-x}Al_x$ thin film has $L2_1$ or B2 single phase structure, M of the thin film consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.

[0018] The substrate may be such that said $Co_2MGa_{1-x}Al_x$ thin film is formed thereon by heating at 500℃ or lower including non-heating, or said formed thin film is further annealed at 500℃ or lower. Said substrate may be either one of thermally oxidized Si, glass, MgO single crystal, GaAs single crystal, or Al_2O_3 single crystal. A buffer layer may be provided between the substrate and $Co_2MGa_{1-x}Al_x$ thin film. As this buffer layer, at least either one of Al, Cu, Cr, Fe, Nb, Ni, Ta, and NiFe may be used.

[0019] According to this constitution, $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq$

7.5, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film or merely $Co_2MGa_{1-x}Al_x$ thin film), which is ferromagnetic at room temperature, and a half metal having high spin polarizability can be obtained.

[0020] A tunnel magnetoresistance effect device of the present invention is characterized to be made of $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film in which at least one of ferromagnetic layers has $L2_1$ or B2 single phase structure in the tunnel magnetoresistance effect device having a plurality of ferromagnetic layers on a substrate.

[0021] In said constitution, the ferromagnetic layer preferably consists of a fixed layer and a free layer, and the free layer is the $Co_2MGa_{1-x}Al_x$ magnetic thin film having $L2_1$ or B2 single phase structure. Said substrate may be such that $Co_2MGa_{1-x}Al_x$ magnetic thin film is formed thereon by heating at 500℃ or lower including non-heating, or by further annealing said formed thin film at 500℃ or lower. Said substrate may be either one of thermally oxidized Si, glass, MgO single crystal, GaAs single crystal, or Al_2O_3 single crystal. A buffer layer may be provided between the substrate and $Co_2MGa_{1-x}Al_x$ thin film. Said buffer layer may be made of at least either one of Al, Cu, Cr, Fe, Nb, Ni, Ta, or NiFe.

According to the constitution described above, a tunnel magnetoresistance effect device of large TMR in the low external magnetic field at room temperature can be obtained.

[0022] A giant magnetoresistance effect device of the present invention is characterized to be made of $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film in which at least one of ferromagnetic layers has $L2_1$ or B2 single phase structure in the giant magnetoresistance effect device having a plurality of ferromagnetic layers on a substrate, and to have a structure in which electric current flows in the direction perpendicular to the film surface.

[0023] Said ferromagnetic layer preferably consists of a fixed layer and a free layer, and the free layer is preferably made of $Co_2MGa_{1-x}Al_x$ ($0 \leqq x \leqq 0.7$) magnetic thin film having $L2_1$ or B2 single phase structure. Said substrate may be such that $Co_2MGa_{1-x}Al_x$ thin film is formed thereon by heating at 500℃ or lower including non-heating, or by further annealing said formed thin film at 500℃ or lower. A buffer layer may be provided between the substrate and $Co_2MGa_{1-x}Al_x$ thin film. Said substrate may be either one of thermally oxidized Si, glass, MgO single crystal, GaAs single crystal, or Al_2O_3 single crystal. Said buffer layer may be made of at least either one of Al, Cu, Cr, Fe, Nb, Ni, Ta, or NiFe.

According to the constitution described above, a giant magnetoresistance effect device of large GMR in the low external magnetic field at room temperature can be obtained.

[0024] A magnetic device of the present invention is characterized in that the $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film having $L2_1$ or B2 single phase structure is formed on a substrate. In this case, either a tunnel or a giant magnetoresistance effect device may be used in which a free layer is made of the above-mentioned $Co_2MGa_{1-x}Al_x$ ($0 \leqq x \leqq 0.7$) magnetic thin film.

[0025] A tunnel or a giant magnetoresistance effect device is preferably fabricated by heating a substrate at 500℃ or lower including non-heating to form $Co_2MGa_{1-x}Al_x$ thin film thereon, or by further annealing said formed thin film at 500℃ or lower. A tunnel or a giant magnetoresistance effect device may be used in which a buffer layer is provided between the substrate and $Co_2MGa_{1-x}Al_x$ ($0 \leqq x \leqq 0.7$) thin film. A tunnel or a giant magnetoresistance effect device may be used in which said substrate is either one of thermally oxidized Si, glass, MgO single crystal, GaAs single crystal, or Al_2O_3 single crystal. A tunnel or a giant magnetoresistance effect device may be used in which at least either one of Al, Cu, Cr, Fe, Nb, Ni, Ta, or NiFe is used as the buffer layer.

According to the constitution described above, a magnetic

device using a magnetoresistance effect device of large TMR or GMR in the low external magnetic field at room temperature can be obtained.

[0026] A magnetic head and a magnetic recording device of the present invention is characterized in that the $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film having $L2_1$ or B2 single phase structure is formed on a substrate.

[0027] In the constitution described above, a tunnel or a giant magnetoresistance effect device is preferably used in which a free layer is said $Co_2MGa_{1-x}Al_x$ (where $0 \leqq x \leqq 0.7$) magnetic thin film. A tunnel or a giant magnetoresistance effect device may be used in which $Co_2MGa_{1-x}Al_x$ thin film is formed by heating a substrate at 500℃ or lower including non-heating, or by further annealing said formed thin film at 500 ℃ or lower. A tunnel or a giant magnetoresistance effect device may be used in which a buffer layer is provided between the substrate and $Co_2MGa_{1-x}Al_x$ thin film. A tunnel or a giant magnetoresistance effect device may be used in which the substrate is either one of thermally oxidized Si, glass, MgO single crystal, GaAs single crystal, or Al_2O_3 single crystal. A tunnel or a giant magnetoresistance effect device may be used in which the buffer layer is at least either one of Al, Cu, Cr, Fe, Nb, Ni, Ta, or NiFe.

According to the constitution described above, a magnetic head and a magnetic recording device of large capacity and high speed can be obtained by using a magnetoresistance effect device of large TMR or GMR in the low external magnetic field at room temperature.

Brief Description of the Drawings

[0028]

Fig. 1 is a cross-sectional view illustrating magnetic thin film in accordance with the first embodiment of the present invention.

Fig. 2 is a cross-sectional view illustrating a modified version of magnetic thin film in accordance with said first embodiment.

Fig. 3 is a view diagrammatically illustrating the structure of

explanation and understanding of the present invention.

The present invention will be explained in detail below based on the forms of implementations illustrated in the figures. In each figure, identical marks and symbols are used for identical or corresponding parts.

[0030] The first embodiment of the magnetic thin film of the present invention will be explained first.

Fig. 1 is a cross-sectional view illustrating a magnetic thin film in accordance with the first embodiment of the present invention. As shown in Fig. 1, the magnetic thin film 1 of the present invention is provided with $Co_2MGa_{1-x}Al_x$ thin film 3 on a substrate 2 at room temperature. In the $Co_2MGa_{1-x}Al_x$ thin film 3, M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$, where said valence electron concentration Z of an element in M is defined as $Z_{Ti} = 4$, $Z_V = 5$, $Z_{Cr} = Z_{Mo} = Z_W = 6$, $Z_{Mn} = 7$, and $Z_{Fe} = 8$ for the above-mentioned elements Ti, V, Mo, W, Cr, Mn, and Fe, respectively. In case that M is either Cr, Mo, or W, the average valence electron concentration Z is 6, and hence satisfies $5.5 \leqq Z \leqq 7.5$ above.

[0031] The average valence electron concentration Z in case that M is two species will be explained. Its composition is assumed as $M = M1_aM2_{1-a}$. M1 and M2 are metals selected from the above-mentioned metals M, and their compositions are a for M1 and 1-a for M2. The valence electron concentration Z of M1 and M2 are Z_{M1} and Z_{M2}, respectively. Said average valence electron concentration Z of $M1_aM2_{1-a}$ can be calculated by $Z = a \times Z_{M1} + (1-a) \times Z_{M2}$, and the composition of M may be determined so that Z comes within the range of $5.5 \leqq Z \leqq 7.5$.

[0032] In case that M is two or more species, M may be selected so that the average valence electron concentration Z similarly satisfies $5.5 \leqq Z \leqq 7.5$ from its composition and valence electron concentrations Z. The $Co_2MGa_{1-x}Al_x$ thin film 3 is ferromagnetic at room temperature, has the electrical resistivity of about 200 $\mu\Omega \cdot cm$, and has $L2_1$ or B2 single phase structure without heating the substrate. The film

thickness of $Co_2MGa_{1-x}Al_x$ thin film 3 on the substrate 2 may be 1 nm

or more and 1 μm or less.

[0033] Fig. 2 is a cross-sectional view illustrating a modified version of magnetic thin film in accordance with the first embodiment of the present invention. As shown in Fig. 2, the magnetic thin film 5 of the present invention has additionally a buffer layer 4 inserted between the substrate 2 and $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 in the structure of the magnetic thin film 1 of Fig. 1. By inserting the buffer layer 4, the crystal quality of $Co_2MGa_{1-x}Al_x$ (where $0 \leqq x \leqq 1$) thin film 3 on the substrate 1 can be further improved.

[0034] The substrate 2 used for said magnetic thin films 1 and 5 may be a thermally oxidized Si, a polycrystal of glass or others, or a single crystal of MgO, Al_2O_3, or GaAs or others. As the buffer layer 4, Al, Cu, Cr, Fe, Nb, Ni, Ta, or NiFe may be used.

[0035] The film thickness of said $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 may be 1nm or more and 1 μm or less. With said film thickness less than 1 nm, it is practically difficult to obtain $L2_1$ or B2 single phase structure as described below, and with said film thickness over 1 μm, application such as a spin injection device becomes difficult, and these conditions are not preferred.

[0036] The function of the magnetic thin film used in the first embodiment of the constitution described above will be explained next.

Fig. 3 is a view diagrammatically illustrating the structure of $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) used as the magnetic thin film of said first embodiment. The structure shown in the figure is that eight times as large (twice by a lattice constant) as a common unit lattice of bcc (body-centered cubic lattice).

[0037] In the $L2_1$ structure of $Co_2MGa_{1-x}Al_x$, M is arranged at the position I of Fig. 3 (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo,

W, Cr, Mn, and Fe) so that the composition is such that the average valence electron concentration Z is $5.5 \leqq Z \leqq 7.5$, Ga and Al are arranged at the position II so that the relative composition is $Ga_{1-x}Al_x$ $(0 \leqq x \leqq 0.7)$, and Co is arranged at the positions III and IV.

[0038] In the B2 single phase structure of $Co_2MGa_{1-x}Al_x$, M, Ga, and Al are irregularly arranged at the positions I and II of Fig. 3 (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe), and Co is arranged at the positions III and IV. In this case, the relative composition of M, Fe, and Cr is so adjusted as to be $M_1Ga_{1-x}Al_x$ (where $0 \leqq x \leqq 0.7$).

[0039] The magnetic properties of the magnetic thin films 1 and 5 used in the first embodiment of the above-described constitution will be explained next. The $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 of the constitution as mentioned above is ferromagnetic at room temperature, and the $Co_2MGa_{1-x}Al_x$ thin film of $L2_1$ or B2 single phase structure is obtained without heating the substrate.

[0040] Further, the $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 of the constitution as mentioned above can obtain $L2_1$ or B2 single phase structure even with a very thin film of the film thickness as thin as several nm. The B2 structure of the $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film is similar to $L2_1$ structure, but their difference is that said M and Ga (Al) atoms are regularly arranged in $L2_1$ structure, whereas they are irregularly arranged in the B2 structure. These differences can be measured by X-ray and electron beam diffractions.

[0041] The reason why the average valence electron concentration Z is set as $5.5 \leqq M \leqq 7.5$ for said $Co_2MGa_{1-x}Al_x$ thin film 3 will be explained next. If Z is less than 5.5, the Currie temperature of the

thin film becomes lower than 100℃, and a large TMR can not be attained at room temperature. On the other hand, if Z exceeds 7.5, the

half metal characteristics of the thin film disappears, and, for example, large GMR or TMR can not be attained for a giant magnetoresistance effect device and a tunnel magnetoresistance effect devices both having CPP structures.

[0042] The second embodiment is shown next for the magnetoresistance effect device using the magnetic thin film of the present invention .

Fig. 4 is a view illustrating the cross section of a magnetoresistance effect device using magnetic thin film in accordance with the second embodiment of the present invention. Fig. 4 shows the case of a tunnel magnetoresistance effect device. As shown in this figure, the tunnel magnetoresistance effect device 10 is provided, for example, with the $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 on a substrate 2, and has a sequentially layered structure with an insulation layer 11 as a tunnel layer, a ferromagnetic layer 12, and an antiferromagnetic layer 13. The antiferromagnetic layer 13 is used to fix a spin of the ferromagnetic layer 12 for a so-called spin valve type structure. In said structure, the $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 is called a free layer, and the ferromagnetic layer 12 is called a pin layer. Here, the ferromagnetic layer 12 may have either a single layer structure or a plural layer structure. Al_2O_3 or AlO_x as an oxide of Al can be used as the insulation layer 11, CoFe, NiFe, or a combination film of CoFe and NiFe and others can be used as the ferromagnetic layer 12, and IrMn and others can be used as the antiferromagnetic layer 13.

[0043] Further, a non-magnetic electrode layer 14 is preferably deposited as a protective film on the antiferromagnetic layer 13 of the tunnel magnetoresistance effect device 10 of the present invention.

Fig. 5 is a view illustrating the cross section of a modified version of a magnetoresistance effect device using magnetic thin film

in accordance with the second embodiment of the present invention. A

tunnel magnetoresistance effect device 15 as a magnetoresistance effect device using magnetic thin film of the present invention is provided with a buffer layer 4 and the $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 on the substrate 2, and has a sequentially layered structure with the insulation layer 11 as the tunnel layer, the ferromagnetic layer 12, the antiferromagnetic layer 13, and a non-magnetic electrode layer 14 as a protective layer. The difference of Fig. 5 from Fig. 4 in the structure is that the buffer layer 4 is provided to the structure of Fig. 4. All other structures are same as Fig. 4.

[0044] Fig. 6 is a view illustrating the cross section of a modified version of a magnetoresistance effect device using magnetic thin film in accordance with the second embodiment of the present invention. A tunnel magnetoresistance effect device 20 as the magnetoresistance effect device using magnetic thin film of the present invention is provided with a buffer layer 4 and $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 16, the antiferromagnetic layer 13, and the non-magnetic electrode layer 14 as the protective layer on the substrate 2 in the sequentially layered structure. The difference of Fig. 6 from Fig. 5 in the structure is that the magnetic thin film of the present invention $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 16 is used also for the ferromagnetic layer 12 as the pin layer of Fig. 4. All other structures are same as Fig. 5.

[0045] When a voltage is applied to the tunnel magnetoresistance effect devices 10, 15, and 20, it is applied between $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 or a buffer layer 4 and the electrode layer 14. As the method to flow electric current

from the buffer layer 4 to

the electrode layer 14, the CPP structure to flow the electric current in the direction perpendicular to the film surface may be employed.

[0046] Here, the substrate 2 used for said tunnel magnetoresistance effect devices 10, 15, and 20 may be such a thermally oxidized Si, polycrystal such as glass, or such a single crystal as MgO, Al_2O_3, and GaAs. As the buffer layer 4, Al, Cu, Cr, Fe, Nb, Ni, Ta, NiFe, or others may be used. The film thickness of said $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 may be 1 nm or more and 1 μm or less. If said film thickness is less than 1 nm, then it becomes difficult to practically obtain $L2_1$ or B2 single phase structure, and if it exceeds 1 μm, its application as the tunnel magnetoresistance effect device becomes difficult, and both cases are not preferable. The tunnel magnetoresistance effect devices 10, 15, and 20 of the present invention constituted as described above can be fabricated by such an ordinary thin film forming method as a sputtering method, a vapor deposition method, a laser ablation method, and an MBE method, and a masking process to form an electrode of the pre-determined shape or others.

[0047] The operation of tunnel magnetoresistance effect devices 10 and 15 as magnetoresistance effect devices using magnetic thin film of the present invention will be explained next.

In case of magnetoresistance effect devices 10 and 15 using magnetic thin film of the present invention, only the spin of the ferromagnetic layer $Co_2MGa_{1-x}Al_x$ as the other free layer (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 is inverted, since two ferromagnetic layers 3 and 12 are used, an antiferromagnetic layer 13 approaches one of them, and a spin valve type to fix the spin of the approaching ferromagnetic layer 12 (pin layer) is used. Therefore, the parallel or the antiparallel state of spins of $Co_2MGa_{1-x}Al_x$ as a free layer (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron

concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film

3 can be attained easily, since spins are fixed in one direction for magnetization of the ferromagnetic layer 12 by spin valve effect by the exchange interaction with the antiferromagnetic layer 13. In this case, the antimagnetic field is small so that magnetic inversion can be caused by as small magnetic field, since magnetization of $Co_2MGa_{1-x}Al_x$ as a free layer (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 is small. Therefore, the magnetoresistance effect devices 10 and 15 of the present invention are suitable to such magnetic devices requiring magnetic inversion by low power as MRAM.

[0048] The operation of tunnel magnetoresistance effect device 20 as a magnetoresistance effect device using magnetic thin film of the present invention will be explained next.

Since the tunnel magnetoresistance effect device 20 uses the same $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) as the ferromagnetic $Co_2MGa_{1-x}Al_x$ as the free layer for the ferromagnetic layer 16 of the pin layer, the denominator of the equation (1) mentioned above becomes smaller, and further TMR of the tunnel magnetoresistance effect device of the present invention becomes larger. Therefore, the tunnel magnetoresistance effect device 20 of the present invention is suitable to such magnetic devices requiring magnetic inversion by low power as MRAM.

[0049] The third embodiment of the magnetoresistance effect device using magnetic thin film of the present invention will be explained next.

Fig. 7 is a view illustrating the cross section of a magnetoresistance effect device using magnetic thin film in accordance with the third embodiment of the present invention. The magnetoresistance effect device using magnetic thin film of the present invention shows the case of a giant magnetoresistance effect device. As is shown in the figure, the giant magnetoresistance effect

device 30 is provided with a buffer layer 4 and $Co_2MGa_{1-x}Al_x$ of the

present invention as a ferromagnetic thin film 3 (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.), a non-magnetic metal layer 21, a ferromagnetic layer 22, and a non-magnetic electrode layer 14 as a protective layer on a substrate 2 in the sequentially layered structure.

[0050] Here, a voltage is applied between the buffer layer 4 and the electrode layer 14 of the giant magnetoresistance effect device. The external magnetic field is also applied in parallel in a film plane. The method to flow electric current from the buffer layer 4 to the electrode layer 14 may be both CIP structure of the type to flow electric current in a film plane and CPP structure of the type to flow electric current in the direction perpendicular to a film plane.

[0051] Fig. 8 is a view illustrating the cross section of a modified version of a magnetoresistance effect device using magnetic thin film in accordance with said third embodiment of the present invention. The difference of the giant magnetoresistance effect device 35 of the present invention from the giant magnetoresistance effect device 30 as shown in Fig. 7 is that an antiferromagnetic layer 13 is provided between the ferromagnetic layer 22 and the electrode layer 14 to employ a giant magnetoresistance effect device of a spin valve type. Other structures are same as that shown in Fig. 7 so the explanation is omitted. The antiferromagnetic layer 13 has a function to fix the spin of the ferromagnetic layer 22 as a pin layer in the vicinity. A voltage is applied between the buffer layer 4 and the electrode layer 14 of the giant magnetoresistance effect devices 30 and 35. The external magnetic field is also applied in parallel in a film plane. The method to flow electric current from the buffer layer 4 to the electrode layer 14 may be both CIP structure of the type to flow electric current in a film plane and CPP structure of the type to flow electric current in the direction perpendicular to a film plane.

[0052] As the substrate 2 of said giant magnetoresistance effect devices 30 and 35, such a thermally oxidized Si, polycrystal such as glass and others, or further such a single crystal as MgO, Al_2O_3, GaAs and others may be used. As the buffer layer 4, Al, Cu, Cr, Fe, Nb, Ni,

Ta, NiFe, or others may be used. As the non-magnetic metal layer 21, Cu, Al, or others may be used. As the ferromagnetic layer 22, either one of CoFe, NiFe, or $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film, or a complex film made of these materials may be used. As the antiferromagnetic layer 13, IrMn or others may be used.

[0053] The film thickness of said $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 may be 1 nm or more and 1 μm or less. If said film thickness is less than 1 nm, then it becomes difficult to practically obtain $L2_1$ or B2 single phase structure, and if it exceeds 1μm, its application as a giant magnetoresistance effect device becomes difficult, and both cases are not preferable. The giant magnetoresistance effect devices 30 and 35 of the present invention constituted as described above can be fabricated by such an ordinary thin film forming method as a sputtering method, a vapor deposition method, a laser ablation method, and an MBE method, and a masking process to form an electrode of the pre-determined shape or others.

[0054] Since the ferromagnetic layer $Co_2MGa_{1-x}Al_x$ of the giant magnetoresistance effect device 30 as the magnetoresistance effect device using the magnetic thin film of the present invention (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 is a half metal, its spin polarizability is large. Therefore, only one of the spins of said thin film 3 contributes the conductivity when the external magnetic field is applied. Consequently, very large magnetic resistance i.e. GMR can be obtained by the giant magnetoresistance effect device 30.

[0055] Next, in case of the giant magnetoresistance effect device 35 of a spin valve type as a magnetoresistance effect device using a magnetic thin film, the spin of the ferromagnetic layer 22 as the pin layer is fixed by an antiferromagnetic layer 13, and the spin of the

$Co_2MGa_{1-x}Al_x$ thin film 3 as the free layer (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and

an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) takes the parallel or the antiparallel state by applying the external magnetic field. Since only one of the spins of the half metal $Co_2MGa_{1-x}Al_x$ thin film 3 (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) contributes the conductivity, the very large GMR can be obtained.

[0056] Next, the fourth embodiment of the magnetic device using the magnetoresistance effect device with magnetic thin film of the present invention is shown.

As shown in Figs.1 – 8, the various magnetoresistance effect devices using magnetic thin film of the present invention have very large TMR or GMR in low magnetic field at room temperature.

Fig. 9 is a view diagrammatically illustrating the resistance when the external magnetic field is applied to the tunnel or the giant magnetoresistance effect device as the magnetoresistance effect device using magnetic thin film of the present invention. The abscissa of the figure shows the external magnetic field applied to the magnetoresistance effect device using magnetic thin film of the present invention, and the ordinate shows the resistance. To the magnetoresistance effect device using magnetic thin film of the present invention is sufficiently applied the necessary voltage to obtain the giant or the tunnel magnetoresistance effect.

[0057] As is illustrated, the resistance of the magnetoresistance effect device using magnetic thin film of the present invention shows remarkable change by the external magnetic field. When the external magnetic field is applied from the region (I), it is reduced to zero, and it is further inverted and increased, then in the regions (II) and (III) the resistance changes from minimum to maximum. Here, the external magnetic field in the region (II) is defined as H_1.

[0058] When the external magnetic field is further increased, the resistance change is obtained from the region (III) to the region (V) via the region (IV). Thereby, the spins of the ferromagnetic layer 22 and the $Co_2MGa_{1-x}Al_x$ as the free layer (where M consists either of Mo,

W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an

average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) thin film 3 become parallel in the magnetoresistance effect device using magnetic thin film of the present invention in the external magnetic field of the regions (I) and (V) to be the minimum resistance, and said spin becomes antiparallel in the region (III) to be the maximum resistance. As the $Co_2MGa_{1-x}Al_x$ thin film 3, $Co_2FeCrGa$, for example, may be used.

[0059] The magnetoresistance change is expressed by the Equation (2) below when external magnetic field is applied, and the larger this value, the more preferable as the magnetoresistance change.

magnetoresistance change(%)
= (maximum resistance− minimum resistance)/minimum resistance (2).

Thereby, the magnetoresistance effect device using magnetic thin film of the present invention can attain large magnetoresistance change, as shown in Fig. 9, by applying the magnetic field from zero to slightly larger than H_1, that is, low magnetic field.

[0060] As explained in Fig. 9, since the magnetoresistance effect device using magnetic thin film of the present invention shows large TMR or GMR at room temperature in low magnetic field, if used as a magnetoresistance sensor, a magnetic device of high sensitivity can be obtained. Since the magnetoresistance effect device using magnetic thin film of the present invention shows large TMR or GMR at room temperature in low magnetic field, it can be applied to the readout magnetic heads of high sensitivity, and various magnetic recording devices using said magnetic heads. MTJ devices, for example, which are the magnetoresistance effect devices using magnetic thin film of the present invention, are arranged in matrix, and are applied with the external magnetic field by flowing electric current in the separately provided interconnection. By controlling the magnetization of the ferromagnet as the free layer composing said MTJ devices to parallel or antiparallel by external magnetic field, “1” or “0” are recorded. Further by readout utilizing TMR effect, a magnetic device such as MRAM can be realized. Since GMR is large in a GMR device of

Example 3

[0066] The tunnel magnetoresistance effect device 15 of the same spin valve type as Example 2 was fabricated by using Co_2CrGa thin film 3 except that its film thickness was 100 nm. By applying the external magnetic field to said tunnel magnetoresistance effect device 15, the magnetoresistance was measured at room temperature. Fig. 12 is a view illustrating the magnetic field dependency of the resistance of the tunnel magnetoresistance effect device 15 of Example 3. The abscissa of the figure shows the external magnetic field H (Oe), and the ordinate shows the resistance (Ω). The magnetoresistance including also its hysteresis characteristics was measured by sweeping the external magnetic field. Hereby, the TMR was determined as 3.2 %.

[0067] In Examples 2 and 3, no plateau was seen in TMR curves, and the perfect antiparallel state of spins was not realized. By optimizing the fabrication conditions of the tunnel magnetoresistance effect device 15, a TMR will be made dramatically larger.

Industrial Applicability

[0068] In accordance with the present invention, $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film having $L2_1$ or B2 single phase structure can be fabricated at room temperature without heating. Further, it shows the ferromagnetic property and the high spin polarizability.

[0069] Also, with a giant magnetoresistance effect device using $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film having $L2_1$ or B2 single phase structure, the extremely large GMR can be attained at room temperature in low external magnetic field. Also with the tunnel magnetoresistance effect device, quite large TMR can be similarly attained.

[0070] Further by applying various magnetoresistance effect devices

of the present invention using $Co_2MGa_{1-x}Al_x$ (where M consists either of Mo, W, or Cr, or of two or more of Ti, V, Mo, W, Cr, Mn, and Fe, and an average valence electron concentration Z of M is $5.5 \leqq Z \leqq 7.5$, and x is $0 \leqq x \leqq 0.7$.) magnetic thin film having $L2_1$ or B2 single phase structure to such various magnetic devices as the magnetic heads of super gigabit large capacity and high speed, or non-volatile and high speed MRAM and the like, novel magnetic devices can be realized. In this case, since the saturation magnetization is small, the magnetic switching field by spin injection becomes small, and magnetization reversal can be realized with low power consumption, as well as it is applicable as the key material to open widely the field of spin electronics, as efficient spin injection to semiconductors becomes possible, and development of spin FET is also possible.